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- (56)
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- Primary Examiner — Vu Le

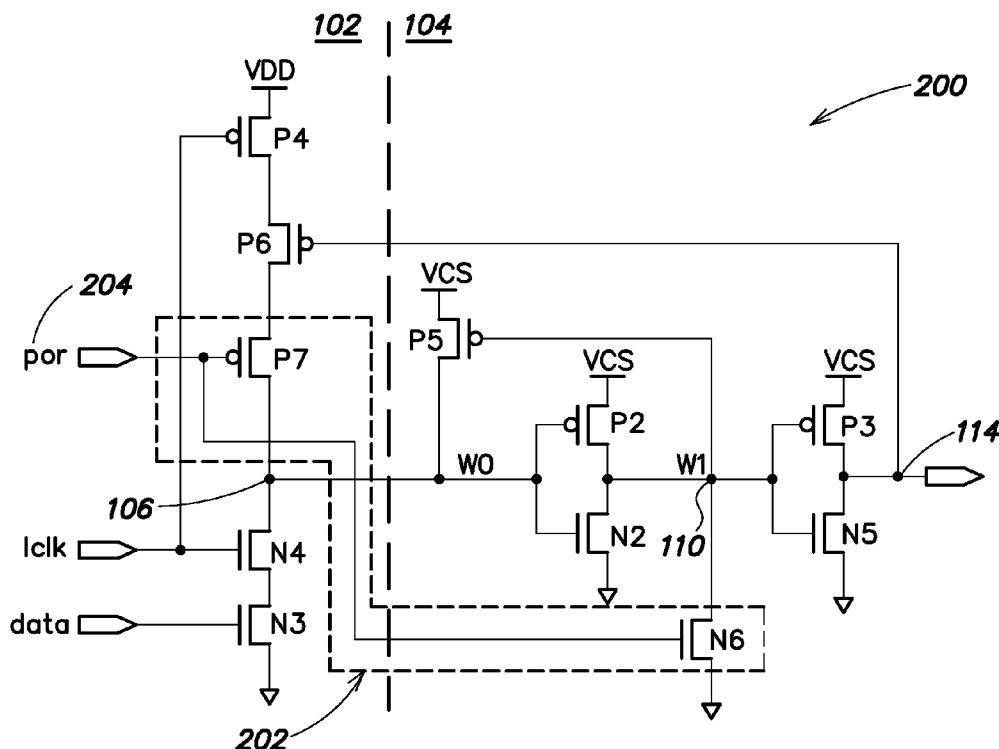
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- (57) **ABSTRACT**

- In a first aspect, a level shifter circuit for use in a memory array is provided that includes (1) a first voltage domain powered by a first voltage; (2) a second voltage domain powered by a second voltage; (3) level shifter circuitry that converts an input signal from the first voltage domain to the second voltage domain; and (4) isolation circuitry that selectively isolates the first voltage domain from the second voltage domain so as to selectively prevent current flow between the first voltage domain and the second voltage domain. Numerous other aspects are provided.

- 20 Claims, 3 Drawing Sheets**

- (52) **U.S. Cl.** 365/189.11; 365/189.15



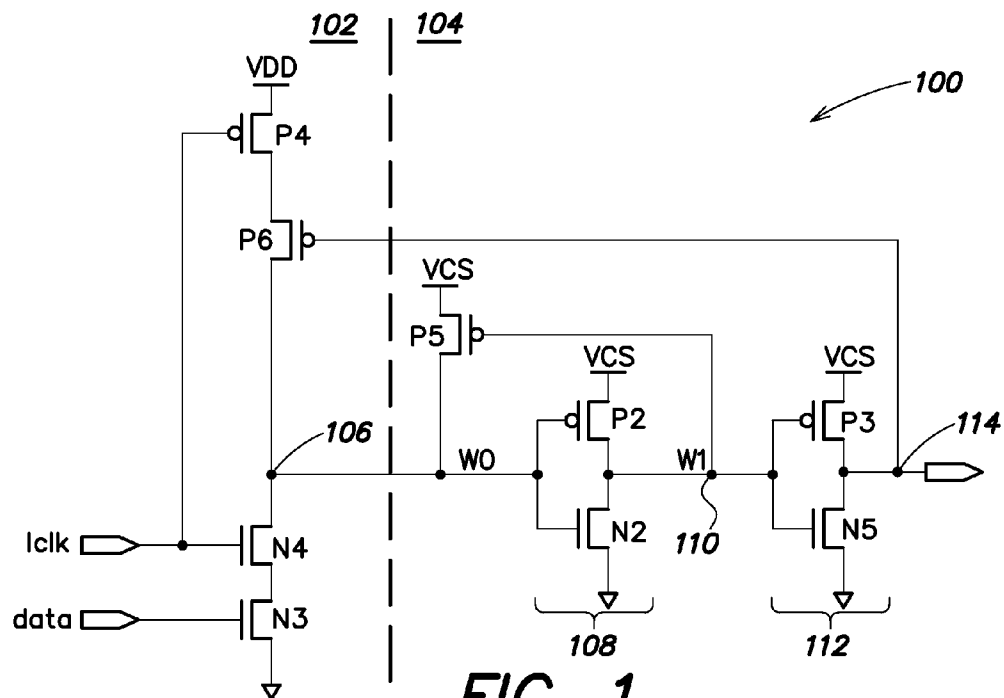


FIG. 1
(Prior Art)

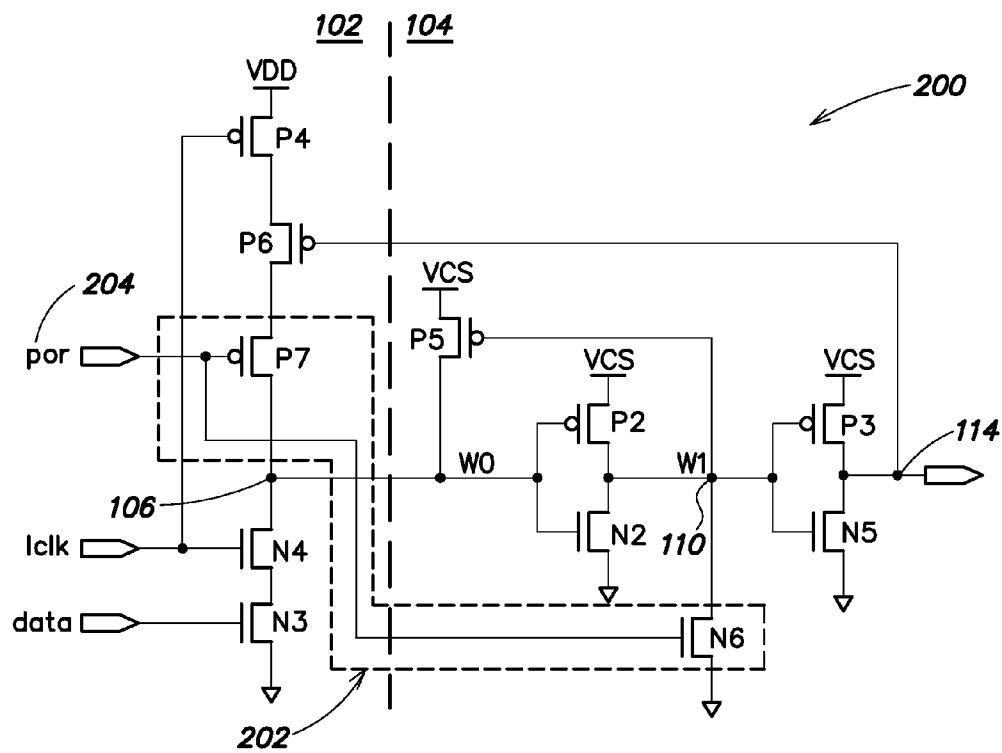


FIG. 2

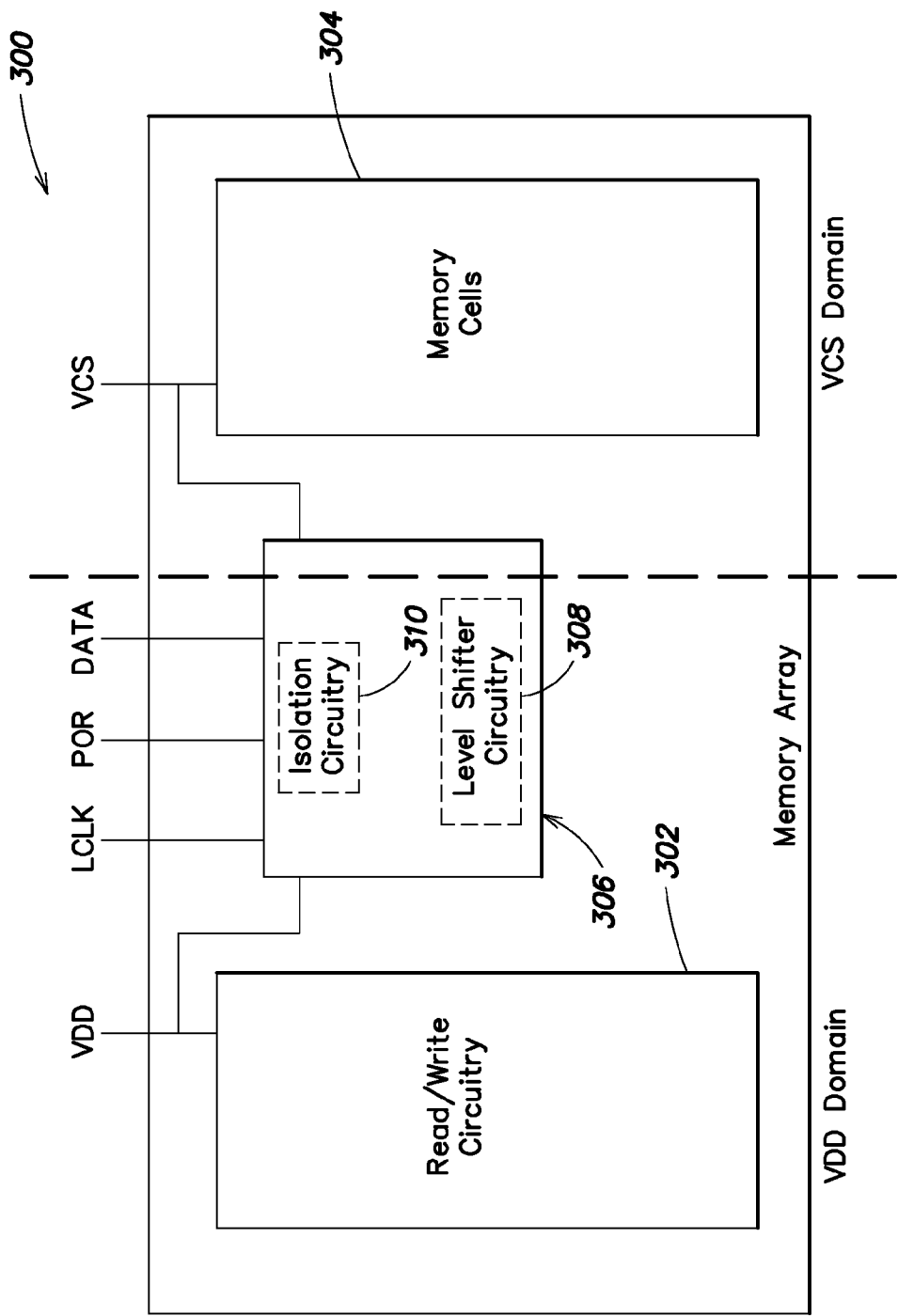
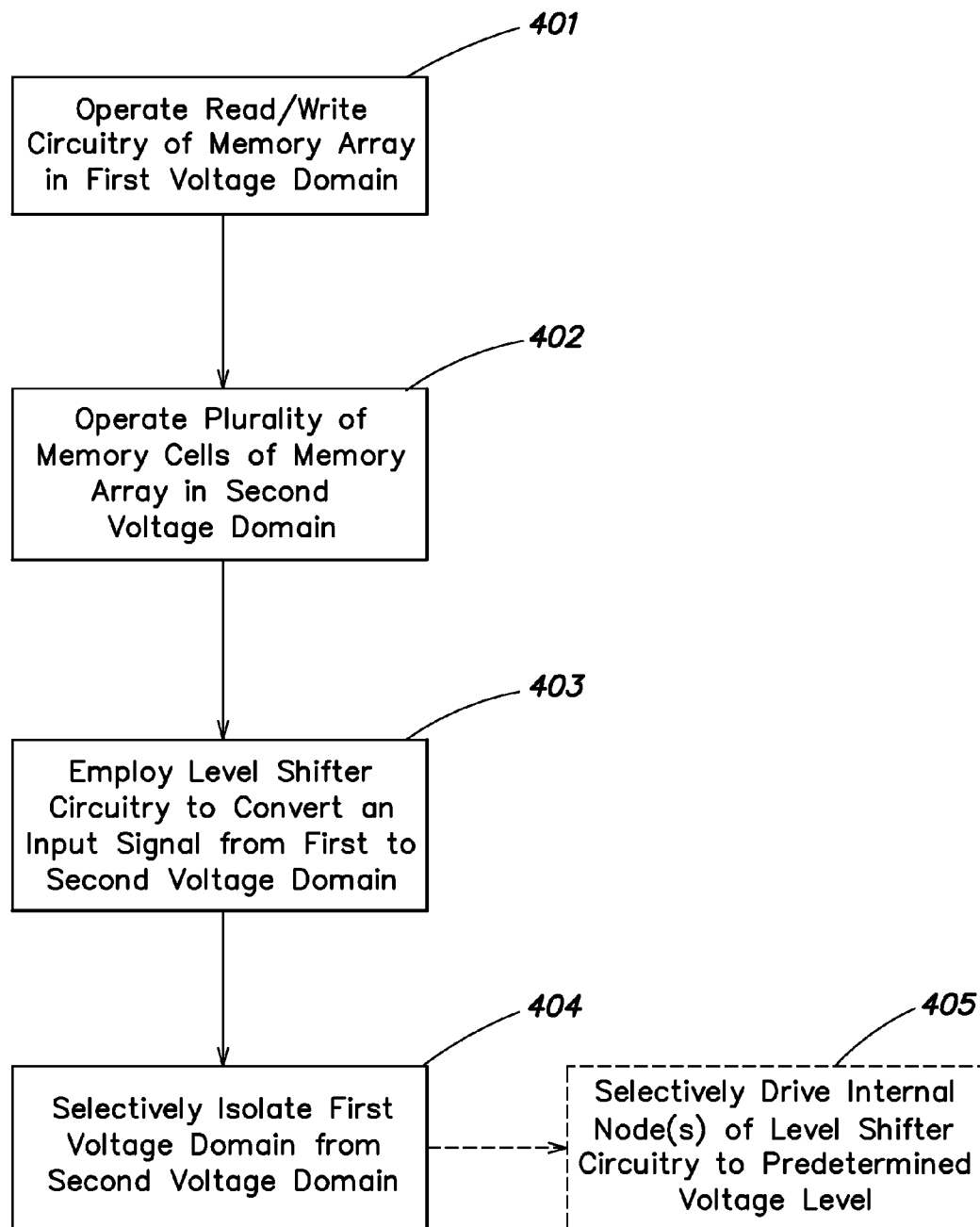


FIG. 3

**FIG. 4**

1

LEVEL SHIFTER FOR USE WITH MEMORY ARRAYS

FIELD OF THE INVENTION

The present invention relates generally to memory arrays, and more particularly to level shifter circuitry for use with memory arrays.

BACKGROUND

As memory devices continue to scale, the power supply voltage (V_{DD}) employed to power these devices is typically reduced. In some cases, a reduced V_{DD} makes it more difficult to retain stored charge in memory devices such as static random access memories (SRAMs).

To improve the stability and performance of SRAM cells, a separate (higher) power supply voltage called V_{CS} has been introduced in addition to the main chip power supply voltage V_{DD} . This secondary, higher voltage V_{CS} provides the voltage required to ensure proper charge storage within memory cells, while allowing the remainder of the devices on a memory chip to operate at a reduced V_{DD} .

While use of a separate power supply voltage V_{CS} may improve the charge storage characteristics of SRAMs, other device issues may arise. For example, V_{CS} is typically held at a slightly higher voltage than the chip supply voltage V_{DD} . For example, V_{CS} may be about 100 mV to 200 mV higher than V_{DD} in some cases. During device operation, however, V_{CS} may occasionally spike to a higher voltage level, such as about 600 mV or higher above V_{DD} . This may prevent transistors within the memory array from turning off, and cause the memory array to fail.

To reduce the affects of voltage spikes in V_{CS} , level shifters may be employed to help separate the V_{CS} and V_{DD} voltage domains, and maintain an acceptable voltage differential between V_{CS} and V_{DD} . However, some prior art level shifters may generate extraneous currents that deleteriously affect memory array operation. Accordingly, a need exists for improved level shifter circuitry for use with memory arrays.

SUMMARY

In a first aspect of the invention, a level shifter circuit for use in a memory array is provided that includes (1) a first voltage domain powered by a first voltage; (2) a second voltage domain powered by a second voltage; (3) level shifter circuitry that converts an input signal from the first voltage domain to the second voltage domain; and (4) isolation circuitry that selectively isolates the first voltage domain from the second voltage domain so as to selectively prevent current flow between the first voltage domain and the second voltage domain.

In a second aspect of the invention, a memory array is provided that includes (1) read/write circuitry that operates in a first voltage domain; (2) a plurality of memory cells that operate in a second voltage domain that is higher than the first voltage domain; (3) level shifter circuitry that converts an input signal from the first voltage domain to the second voltage domain; and (4) isolation circuitry that selectively isolates the first voltage domain from the second voltage domain so as to selectively prevent current flow between the first voltage domain and the second voltage domain.

In a third aspect of the invention, a method of operating a memory array is provided that includes (1) operating read/write circuitry of the memory array in a first voltage domain; (2) operating a plurality of memory cells of the memory array

2

in a second voltage domain that is higher than the first voltage domain; (3) employing level shifter circuitry of the memory array to convert an input signal of the memory array from the first voltage domain to the second voltage domain; and (4) employing isolation circuitry of the memory array to selectively isolate the first voltage domain from the second voltage domain so as to selectively prevent current flow between the first voltage domain and the second voltage domain. Numerous other aspects are provided.

Other features and aspects of the present invention will become more fully apparent from the following detailed description, the appended claims and the accompanying drawings.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 is a schematic representation of a prior art level shifter.

FIG. 2 is a schematic representation of a level shifter in accordance with an embodiment of the present invention.

FIG. 3 is a schematic illustration of an exemplary memory array provided in accordance with the present invention.

FIG. 4 is a flowchart of an exemplary method of operating the memory array of FIG. 3 in accordance with the present invention.

DETAILED DESCRIPTION

As stated, level shifters may be employed to reduce the affects of voltage spikes in V_{CS} by helping to separate the V_{CS} and V_{DD} voltage domains, and maintaining an acceptable voltage differential between V_{CS} and V_{DD} . However, prior art level shifters typically are designed with the assumption that V_{CS} will always be higher than V_{DD} , which is not guaranteed.

As will be described further below, during a reset, power up or power down operation of a memory array, V_{CS} may fall below V_{DD} . If V_{CS} drops below V_{DD} in a conventional level shifter circuit, an extraneous current may be generated between the V_{DD} and V_{CS} voltage domains. Such a current may be referred to as a "crowbar current" and may cause the memory array to operate inefficiently and/or fail.

In accordance with the present invention, power on and/or power off (POR) circuitry (also referred to herein as "isolation circuitry") is provided for a level shifter circuit to prevent the above-described unintended crowbar current should V_{CS} fall below V_{DD} during reset, power up and/or power down of a memory array that employs the level shifter circuit. For example, the POR circuitry provided herein may electrically isolate the two voltage domains V_{DD} and V_{CS} from one another, thereby preventing current flow between the two power supply rails.

The inventive POR circuitry also may drive an internal state of the level shifter circuit to a known state (e.g., a predetermined voltage level) while isolating the two voltage domains V_{DD} and V_{CS} . This may be particularly important when the level shifter circuit is used for a wordline driver. Having the level shifter circuit reside in an unknown state may result in multiple wordlines firing at the same time. Memory arrays are designed to operate by firing only one wordline at a time, and firing multiple wordlines even at power on or reset may be problematic (e.g., lead to memory errors and/or device failure). These and other embodiments of the invention are described below with reference to FIGS. 1-4.

FIG. 1 is a schematic representation of a conventional level shifter 100 that may be employed within a memory array (not separately shown). In general, numerous level shifter circuits

may be employed within a memory array (e.g., one per wordline). The prior art level shifter **100** may include two voltage domains, such as V_{DD} domain **102** and V_{CS} domain **104**, with specific voltages V_{DD} and V_{CS} , respectively. Exemplary voltages for V_{DD} range from about 0.5 to about 1.5 volts, and exemplary voltages for V_{CS} range from about 1 to about 2 volts, although any other suitable voltages may be used for V_{DD} and/or V_{CS} .

Level shifter **100** also include n-channel metal oxide semiconductor field effect transistors (NFETs) **N3** and **N4** coupled in series between ground and a first node **106**, and p-channel metal oxide semiconductor field effect transistors (PFETs) **P4** and **P6** coupled in series between first node **106** and V_{DD} . The gate of NFET **N3** serves as a data input DATA, while the gate of NFET **N4** serves as a clock input LCLK. The gates of NFET **N4** and PFET **P4** are coupled together.

A PFET **P5** is coupled between first node **106** and V_{CS} . NFET **N2** and PFET **P2** are coupled in series between ground and V_{CS} and serve as a first CMOS inverter **108** between first node **106** and a second node **110**. NFET **N5** and PFET **P3** are coupled in series between ground and V_{CS} and serve as a second CMOS inverter **112** between second node **110** and a third node **114**. The gate of PFET **P5** is coupled to second node **110**, and the gate of PFET **P6** is coupled to third node **114**.

V_{DD} domain **102** encompasses those devices of the level shifter **100** that are powered by V_{DD} . V_{DD} domain **102** generally encompasses the area to the left of the dotted line. V_{CS} domain **104** encompasses those devices of the level shifter **100** that are powered by V_{CS} . V_{CS} domain **104** generally encompasses the area to the right of the dotted line.

V_{DD} may be the core logic voltage used in read/write circuits of the memory array (not separately shown) employing level shifter **100**. That is, V_{DD} may be the voltage difference from ground used by circuitry of the memory array other than memory cells. V_{DD} may or may not be applied to bit lines. To reduce power consumption of the memory array, V_{DD} may be reduced below what typically would be employed for storing charge within memory cells, while still allowing operation of read/write circuits and other devices of the memory array.

V_{CS} is a memory cell specific voltage, separate and in addition to V_{DD} . During normal operation of a memory array, V_{CS} is larger than V_{DD} so as to provide the voltage required to ensure proper charge storage within each memory cell of the memory array. In this manner, memory array stability and performance are improved.

Referring again to FIG. 1, operation of the conventional level shifter **100** is now described.

During normal operation of level shifter **100**, V_{CS} is larger than V_{DD} , and DATA on the gate of NFET **N3** is clocked into level shifter **100** when LCLK goes high on the gate of NFET **N4**. Specifically, with LCLK high, NFET **N4** is on and PFET **P4** is off. If DATA is high, NFET **N3** is on and first node **106** is pulled low (e.g., to ground). Second node **110** is high and third node **114** is low. With second node **110** high, PFET **P5** is off. With third node **114** low, PFET **P6** is on.

With LCLK high and DATA low, NFET **N3** is off. First node **106** rises from its low voltage due to V_{DD} being dropped across PFET **P4** which is off and NFET **N3** which is off. Second node **110** switches low, turning PFET **P5** on, which pulls first node **106** to V_{CS} . Third node **114** switches high to V_{CS} and PFET **P6** turns off.

Thus, during normal operation of the level shifter **100**, DATA present on the gate of NFET **N3** is inverted and output at third node **114**. Furthermore, DATA swings between ground and V_{CS} at third node **114** (in V_{CS} domain **104**), rather than between ground and V_{DD} as it does in V_{DD} domain **102**.

When V_{CS} is larger than V_{DD} , level shifter **100** functions as described above. However, if V_{CS} drops below V_{DD} , such as during reset, power up or power down of the memory array, an extraneous current may flow between V_{DD} domain **102** and V_{CS} domain **104**. Such a current may consume significant power resources and/or damage the memory array. For example, with first node **106** high, second node **110** is low and third node **114** is high. With second node **110** low, PFET **P5** is on and first node **106** is held at V_{CS} . The gate of PFET **P6** is similarly held at V_{CS} by PFET **P3** being on (when second node **110** is low). If LCLK is low, PFET **P4** is on and the source of PFET **P6** is held at V_{DD} . If V_{CS} falls below V_{DD} by more than the threshold voltage of PFET **P6**, PFET **P6** will start to turn on, creating a current path from V_{DD} to V_{CS} through PFETs **P4**, **P6** and **P5**. Accordingly, a large extraneous "crowbar" current may result during each low cycle of LCLK. As stated, such a current may consume significant power resources and/or damage the memory array.

In accordance with the present invention, power on and/or power off (POR) circuitry is provided for a level shifter circuit that prevents the above-described unintended crowbar current should V_{CS} fall below V_{DD} during reset, power up and/or power down of a memory array that employs the level shifter circuit. For example, the POR circuitry may selectively isolate the V_{DD} voltage domain from the V_{CS} voltage domain so as to selectively prevent current flow between the V_{DD} voltage domain and the V_{CS} voltage domain during reset, power up and/or power down of the memory array.

The inventive POR circuitry also may drive an internal state of the level shifter circuit to a known state while isolating the two voltage domains V_{DD} and V_{CS} from one another. This may be particularly important when the level shifter circuit is used for a wordline driver. Having the level shifter circuit reside in an unknown state may result in multiple wordlines firing at the same time. Memory arrays are designed to operate by firing only one wordline at a time, and firing multiple wordlines even at power on or reset may be problematic (e.g., lead to memory errors and/or device failure).

FIG. 2 is a schematic representation of a level shifter **200** in accordance with an embodiment of the present invention. Level shifter **200** is similar to level shifter **100** of FIG. 1, but includes POR circuitry **202** for preventing crowbar currents between the V_{DD} domain **102** and V_{CS} domain **104**.

With reference to FIG. 2, POR circuitry **202** includes PFET **P7** coupled in series between NFET **N4** and PFET **P6**, and NFET **N6** coupled between second node **110** and ground. The gates of PFET **P7** and NFET **N6** are coupled together and serve as a POR input **204**. In some embodiments, PFET **P7** may be replaced with an NFET and NFET **P6** may be replaced with a PFET and an opposite polarity POR signal may be applied at POR input **204**. In yet other embodiments, other suitable switching devices may be employed in place of PFET **P7** and/or NFET **N6**.

During normal (steady-state) operation of level shifter **200**, such as after power up, before power down or any time V_{CS} is greater than V_{DD} , the POR circuitry **202** may be disabled by applying a low voltage level to POR input **204**. When a low voltage is applied to POR input **204**, PFET **P7** is on and NFET **N6** is off so that these transistors have no effect on the operation of the level shifter **200**. Specifically, level shifter **200** will operate similarly to level shifter **100** as described above.

During reset, power on, power off or at any other time when it is believed that V_{CS} may fall below V_{DD} , POR circuitry **202** may be employed to isolate V_{DD} domain **102** from V_{CS} domain **104**, thereby preventing current flow between the power supply rails. The inventive POR circuitry **202** also may drive an internal state of the level shifter circuit **200** to a

5

known state while isolating the two voltage domains. For example, if a high voltage is applied to POR input **204**, PFET **P7** is off. This isolates first node **106** from V_{DD} and prevents current flow between V_{DD} domain **102** and V_{CS} domain **104** should PFETs **P4**, **P6** and **P5** turn on (as previously described when LCLK is low and V_{CS} falls below V_{DD}). Further, with POR input **204** high, NFET **N6** is on and second node **110** is pulled to a low voltage level (e.g., ground). This ensures that PFET **P5** is on and first node **106** is pulled to V_{CS} , and third node **114** is high and the gate of PFET **P6** is high (e.g., so that PFET **P6** is off unless V_{CS} drops below V_{DD} by more than the threshold voltage of PFET **P6**). Level shifter **200** thus remains in a known state.

In summary, POR circuitry **202** may be used to isolate PFET **P6** from PFET **P5** of level shifter **200**. When POR input **204** is high, PFET **P7** is off, isolating the V_{DD} domain **102** from the V_{CS} domain **104**. Although this may succeed in isolating the two voltage domains from one another, it alone may not drive the internal nodes of level shifter **200** to a known state. In order to accomplish this, NFET **N6** may be added. When POR input **204** is high, NFET **N6** is on, driving internal node **110** to ground, a predetermined or known state. By using POR circuitry **202**, V_{DD} domain **102** and V_{CS} domain **104** may be isolated from one another so that extraneous crowbar current will not flow between V_{DD} domain **102** and V_{CS} domain **104** should V_{CS} drop below V_{DD} .

FIG. 3 is a schematic illustration of an exemplary memory array **300** provided in accordance with the present invention. Memory array **300** includes read/write circuitry **302** for reading data from and/or writing data to a plurality of memory cells **304**. Read/write circuitry **302** operates primarily in the V_{DD} voltage domain, while memory cells **304** operate primarily in the V_{CS} voltage domain. Level shifter circuit **306** is provided for converting data and/or other signals from the V_{DD} voltage domain to the V_{CS} voltage domain via level shifter circuitry **308**.

Level shifter circuit **306** includes isolation circuitry **310** that may be employed to selectively isolate the V_{DD} and V_{CS} voltage domains in response to a POR input. For example, the V_{DD} and V_{CS} voltage domains may be isolated from one another during reset, power up, power down and/or any other time V_{CS} may drop below V_{DD} so as to avoid extraneous current flow therebetween (as previously described). Level shifter circuit **306** may be similar to the level shifter **200** described previously with reference to FIG. 2. For example, isolation circuitry **310** may be similar to, or the same as, POR circuitry **202** of FIG. 2, and level shifter circuitry **308** may comprise the remaining components of level shifter **200** of FIG. 2. In general, numerous level shifter circuits may be employed within memory array **300** (e.g., one per wordline).

FIG. 4 is a flowchart of an exemplary method of operating the memory array **300** of FIG. 3 in accordance with the present invention. With reference to FIG. 4, in step **401** read/write circuitry **302** is operated in a first voltage domain (e.g., the V_{DD} voltage domain). For example, read/write circuitry **302** may be powered with a V_{DD} rail voltage.

In step **402**, the memory cells **304** are operated in a second voltage domain (e.g., the V_{CS} voltage domain). For example, one or more memory cells may be programmed, erased, and/or refreshed using a V_{CS} rail voltage.

In step **403**, the level shifter circuitry **308** is employed to convert an input signal, such as DATA, from the first voltage domain to the second voltage domain (as previously described with reference to FIG. 2). During steady-state operation of the memory array **300**, the voltage V_{CS} is higher than the voltage V_{DD} .

6

In step **404**, the isolation circuitry **310** of level shifter circuit **306** may be employed to selectively isolate the first and second voltage domains. For example, the first and second voltage domains may be isolated during reset, power up, power down and/or any other time V_{CS} may drop below V_{DD} so as to avoid extraneous current flow between the two voltage domains (as previously described).

If desired, in step **405**, the isolation circuitry **310** also may be employed to selectively drive an internal node of the level shifter circuitry **308** to a predetermined voltage level. For example, an internal node of the level shifter circuitry **308** may be pulled high or low, as described previously with reference to FIG. 2. As mentioned, this may be particularly important when level shifter circuitry **308** is used for a wordline driver.

The foregoing description discloses only exemplary embodiments of the invention. Modifications of the above-disclosed embodiments which fall within the scope of the invention will be readily apparent to those of ordinary skill in the art. For instance, as described, PFET **P7** may be replaced with an NFET and NFET **P6** may be replaced with a PFET and an opposite polarity POR signal may be applied at POR input **204**. In yet other embodiments, other suitable switching devices may be employed in place of PFET **P7** and/or NFET **N6**. Accordingly, while the present invention has been disclosed in connection with exemplary embodiments thereof, it should be understood that other embodiments may fall within the spirit and scope of the invention as defined by the following claims.

The invention claimed is:

1. A level shifter circuit for use in a memory array, comprising:

a first voltage domain powered by a first voltage;
a second voltage domain powered by a second voltage;
level shifter circuitry that converts an input signal from the first voltage domain to the second voltage domain; and
isolation circuitry that selectively isolates the first voltage domain from the second voltage domain so as to selectively prevent current flow between the first voltage domain and the second voltage domain.

2. The level shifter circuit of claim 1, wherein the first voltage is less than the second voltage during steady-state operation of the level shifter circuit.

3. The level shifter circuit of claim 1, wherein the isolation circuitry includes a first switching device that selectively isolates the first voltage domain from the second voltage domain.

4. The level shifter circuit of claim 3, wherein the first switching device comprises a PFET.

5. The level shifter of claim 3, wherein the isolation circuit includes a second switching device that selectively couples an internal node of the level shifter circuitry to a predetermined voltage level.

6. The level shifter circuit of claim 4, wherein the second switching device is an NFET.

7. A memory array comprising:

read/write circuitry that operates in a first voltage domain;
a plurality of memory cells that operate in a second voltage domain that is higher than the first voltage domain;
level shifter circuitry that converts an input signal from the first voltage domain to the second voltage domain; and
isolation circuitry that selectively isolates the first voltage domain from the second voltage domain so as to selectively prevent current flow between the first voltage domain and the second voltage domain.

7

8. The memory array of claim 7, wherein the first voltage is less than the second voltage during steady-state operation of the level shifter circuit.

9. The memory array of claim 7, wherein the isolation circuitry includes a first switching device that selectively isolates the first voltage domain from the second voltage domain.

10. The memory array of claim 9, wherein the first switching device comprises a PFET.

11. The memory array of claim 9, wherein the isolation circuitry includes a second switching device that selectively couples an internal node of the level shifter circuitry to a predetermined voltage level.

12. The memory array of claim 11, wherein the second switching device is an NFET.

13. A method of operating a memory array comprising:
operating read/write circuitry of the memory array in a first voltage domain;

operating a plurality of memory cells of the memory array in a second voltage domain that is higher than the first voltage domain;

employing level shifter circuitry of the memory array to convert an input signal of the memory array from the first voltage domain to the second voltage domain; and

employing isolation circuitry of the memory array to selectively isolate the first voltage domain from the second voltage domain so as to selectively prevent current flow between the first voltage domain and the second voltage domain.

8

14. The method of claim 13 wherein employing the isolation circuitry to selectively isolate the first voltage domain from the second voltage domain comprises employing the isolation circuitry to selectively isolate the first voltage domain from the second voltage domain during at least one of reset, power up and power down of the memory array.

15. The method of claim 13 further comprising selectively coupling an internal node of the level shifter circuitry to a predetermined voltage level while employing the isolation circuitry to selectively isolate the first voltage domain from the second voltage domain.

16. The method of claim 13, wherein the first voltage is less than the second voltage during steady-state operation of the level shifter circuitry.

17. The method of claim 13, wherein the isolation circuitry includes a first switching device that selectively isolates the first voltage domain from the second voltage domain.

18. The method of claim 17, wherein the first switching device comprises a PFET.

19. The method of claim 17, wherein the isolation circuitry includes a second switching device that selectively couples an internal node of the level shifter circuitry to a predetermined voltage level.

20. The method of claim 19, wherein the second switching device is an NFET.

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